Chandra and *XMM-Newton* Observations of the Herbig Be Star TY CrA

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Abstract

We present observations of the intermediate mass pre-main-sequence star (Herbig Be star), TY CrA, with the X-ray observatories Chandra and XMM-Newton. In an observation on Oct. 2000, Chandra detected an X-ray flare above 1 keV, which is reminiscent of flares from the sun and low-mass stars. From a simultaneous fitting of the time-sliced spectra, the X-ray emission is comprised of a cool non-variable component with kT ~0.8 keV, Lx ~1.5e30 ergs s^{-1} and a variable component with kT ~2-3.6 keV, Lx ~2-9e30 ergs s^{-1}. The elemental abundance is ~0.5 solar, which is typical of stellar X-ray plasma. On the other hand, X-ray emission detected during an XMM-Newton observation in Apr. 2001 was about three times brighter than the quiescent level of the Chandra observation. The flux gradually increased by about 40% during 10 ksec in the middle of the observation. The plasma temperature of the hot component is as high as kT ~4 keV, and does not show any significant heating. The spectrum does not show any apparent line features except for an excess at around 1keV probably from Ne and Fe L line emission, and a marginal enhancement near 6.7 keV. The abundance should be ≤0.1 solar, which is significantly smaller than the abundances from our Chandra analysis. This discrepancy may relate to the different abundance distributions for each plasma, for example, made by some elemental selection mechanism, or a non-thermal process during the high state.

1. Introduction

The *ROSAT* and *ASCA* satellites have detected X-ray emission from intermediate-mass pre-main-sequence stars called Herbig Ae/Be (HAeBe) stars (Zinnecker & Pribisch 1994; Skinner & Yamauchi 1996; Yamauchi et al. 1998; Hamaguchi et al. 2000; Hamaguchi 2001). The X-ray luminosity does not have clear correlation with stellar physical parameters such as spectral type and mass loss rate. In the standard theory of stellar evolution, they are not thought to have X-ray emission mechanism that ordinary stars have: magnetic activity on the stellar surface (low-mass stars) or wind activity induced by strong UV acceleration (OB stars). The X-ray emission mechanism is not well understood.

One way to solve this problem is to determine the degree of time variation in the X-ray emission and its spectral distribution. The Herbig Be star, TY CrA is located in the R CrA molecular cloud, which has a famous low-mass protostar cluster. TY CrA was observed several times with *ASCA*, *Chandra* and *XMM-Newton*. In this poster, we present two types of time variability and the X-ray spectrum of the star as detected by *Chandra* and *XMM-Newton*.

2. TY CrA [19:01:40.8, -36:52:34 (J2000)]

- Herbig Be star (B7-9) with Av ~1.0, distance ~130 pc and Age ~3 Myr
- A detached eclipsing binary system with the primary of 3.16 Msolar and secondary of 1.64 Msolar (Kardopolov et al. 1981, Casey et al. 1993, 1995, 1998)
- *ASCA* observed TY CrA three times (Table 1)
  - The flux was constant during the observations.
  - The spectrum of each observation can be reproduced with an absorbed 1T (Mekal) model

Table1. ASCA Observations of TY CrA

Date	Exposure (ksec)	kT (keV)	N_H (10^{21} cm^{-2})	Lx (ergs s^{-1})[b]
94/04/04	38.4	1.8	3	3e30
96/10/18	10.6	1.8	4[a]	3e30
98/10/19	31.5	1.2	6	4e30

[a]The N_h is fixed at the average value of 94/04/04 and 98/10/19.

[b]Intrinsic X-ray luminosity between 0.5 - 10 keV

3. Results

3.1 Chandra Observation (October 7 2000, *exp.* 19.7 ksec)

- Light curve (Figure 1)
  - An X-ray flare was detected (the second reported in a HAeBe star).
  - The light curve shows fast rise and exponential decay with e-folding time of ~3ksec, which are reminiscent of flares from the sun and low-mass stars.
  - Time variability is not seen below 1 keV, which suggests the presence of soft non-variable and hard variable components.
- Spectra (Figure 2, Table 2)
  - Si line emission and plausible Fe K and Mg lines can be seen in the spectrum (though they are not clear in Figure 2).
  - Spectra in four phases (quiescent, flare, flare decay1, flare decay2, see Figure 1 for the definition) can be simultaneously fit by a commonly absorbed thin-thermal plasma (Mekal) model with a cool component and hot component.
  - The plasma temperature is obviously rising during the flare indicative of heating and cooling.
  - The abundance is moderate for observed stellar X-ray plasma (~0.5 solar).
  - N_H (~4e21 cm^{-2}) is consistent with the ASCA result.

3.2 XMM-Newton Observation (April 9 2001, *exp.* 26.4 ksec)

- Light curve (Figure 3)
  - The flux gradually increases in all bands by a factor of ~1.4 in 10ksec.
- Spectra (Figure 4, Table 3)
  - A strong line emission is seen around 1 keV, which probably originates in Ne or Fe L. A weak Fe K line is also seen.
  - Each time-sliced spectrum (bottom, rise and hill phases, see Figure 3 for the definition) can be reproduced by a commonly absorbed 2T (Mekal) model with a Gaussian line for the 1keV hump. The normalization of the Gaussian, which would come from the cool component, does not significantly vary. We thus assume the cool component is non-variable.
  - We test a commonly absorbed 2T thin-thermal plasma (Mekal) model with cool plus 1keV Gaussian component and hot component. The reduced χ^2 of the best-fit is slightly below the 90% confidence level (1.193 for 386 degree of freedom). The best-fit model shows that the hot plasma temperature decreases as the flux rises (kT: 4.7 -> 4.2 keV), but the model with the temperature fixed at the same value shows similar χ^2 (1.196 for 388 degrees of freedom). Therefore we may only say no apparent temperature increase was observed.
  - The abundance in Table 3 is quite small (0.05 solar), but it could be as high as ~0.15 solar for the hot component.
  - N_H (~5.5e21 cm^{-2}) is slightly larger than the Chandra value, but this is probably not a significant difference.

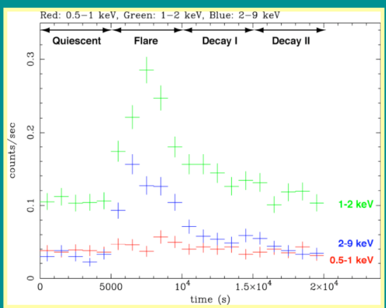

Figure 1. Light curves in the *Chandra* observation

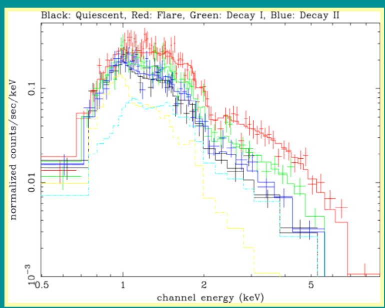

Figure 2. Time-sliced spectra taken with *Chandra*

Table 2. Simultaneous Fitting of the Time-sliced Chandra Spectra

		kT (keV)	Lx (ergs s^{-1}) [a]
Common Cool component		0.81 (0.79-0.87)	1.4e30
Hot component			
Quiescent		2.01 (1.75-2.29)	2.6e30
Flare		3.61 (3.24-4.18)	8.7e30
Decay I		2.79 (2.49-3.15)	4.8e30
Decay II		2.25 (1.99-2.59)	3.2e30
Common Abundance	[solar]	0.50 (0.34-0.67)	
Common N_H	[10^{21} cm^{-2}]	4.2 (3.6-4.5)	
Reduced χ^2 (d.o.f.)		0.94 (196)	

[a] Intrinsic X-ray luminosity between 0.5 - 10 keV

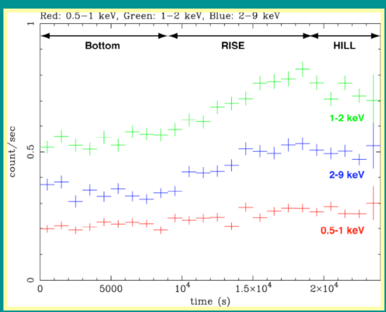

Figure 3. Light curves in the *XMM-Newton* observation

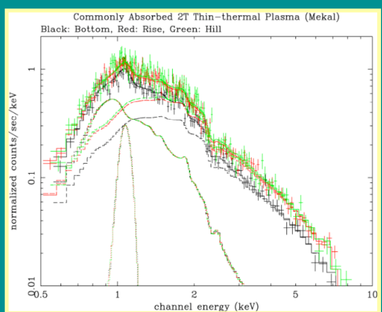

Figure 4. Time-sliced Spectra taken with *XMM-Newton*

Table 3. Simultaneous Fitting of the Time-sliced XMM-Newton Spectra

		kT (keV)	Lx (ergs s^{-1}) [a]
Common Cool component		0.71 (0.68-0.74)	8.2e30
Hot component			
Bottom		4.33 (4.19-4.48)[b]	1.2e31
Rise		com.[b]	1.8e31
Hill		com.[b]	1.9e31
Common Abundance	[solar]	5.5e-2 (4.6e-2-6.1e-2)	
Common N_H	[10^{21} cm^{-2}]	5.5 (5.4-5.6)	
Gauss			
Center	[keV]	5.5 (5.4-5.6)	
Sigma	[keV]	5.0e-2 (3.8e-2-6.6e-2)	
Total photons	[photons cm^{-2} s^{-1}]	1.8e-4 (1.5e-4-2.0e-4)	
Reduced χ^2 (d.o.f.)		1.20 (388)	

[a] Intrinsic X-ray luminosity between 0.5 - 10 keV

[b] The parameter is set at the same value during the fitting.

4. Discussion

- The X-ray flare seen during the *Chandra* observation is reminiscent of low-mass stellar flares. Magnetic activity should be working on TY CrA (the primary or secondary).
- Cool non-variable component during the *Chandra* observation may originate in a coronal region of the primary and/or secondary.
- Even the X-ray flux during "bottom" in the *XMM-Newton* observation is around three times as large as the quiescent phase of the *Chandra* observation and fluxes in earlier *ASCA* observations. The plasma temperature ~4 keV is much higher than those, too. The X-ray activity during the *XMM-Newton* observation would be in a so called 'High State".
- The rise time of X-ray flux during the *XMM-Newton* observation is quite slow.While the spectra do not necessarily need plasma heating. This seems different from the flare seen in the *Chandra* observation and low-mass stellar flares. The flux increase might be caused by another mechanism.
- The elemental abundance in the *Chandra* observation is around 0.5 solar, but that in the *XMM-Newton* is quite small. The X-ray plasma seen during the high state might be produced in a small elemental abundance region, which is made by some elemental selection mechanism, or the emission might be produced by a non-thermal process (TY CrA is a non-thermal radio emitter). Another non-thermal radio source ρ Oph S1 does not show apparent X-ray line emission either (Hamaguchi et al. 2003). The radio emission mechanism may relate to their X-ray emission.

References

Casey B.W., Mathieu R.D., Suntzeff N.B., Lee C, & Cardelli J.A., 1993, AJ, 105, 2276

Casey B.W., Mathieu R.D., Suntzeff N.B., & Walter F.M., 1995, AJ, 109, 2156

Casey B.W., Mathieu R.D., Vaz L.P.R., Andersen J., & Suntzeff N.B., 1998, AJ, 115, 1617

Hamaguchi K., Corcoran M.F., Imanishi K., 2003, PASJ, submitted

Hamaguchi K., 2001, PhD Thesis, Kyoto University

Hamaguchi, K., Terada, H., Bamba, A., & Koyama, K. 2000, ApJ, 532, 1111

Hillenbrand, L. A., Strom, S. E., Vrba, F. J., & Keene, J. 1992, ApJ, 397, 613

Kardopolov V.I., Sahanionok V.V., & Philipjev G.K., 1981, Peremennye Zvezdy, 21, 589

Skinner, S. L., & Yamauchi, S. 1996, ApJ, 471, 987

Zinnecker, H., & Preibisch, T. 1994, A&A, 292, 152